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Article

A Governance Perspective for System-of-Systems

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Abstract: The operating landscape of 21st century systems is characteristically ambiguous, emergent, and uncertain. These characteristics affect the capacity and performance of engineered systems/enterprises. In response, there are increasing calls for multidisciplinary approaches capable of confronting increasingly ambiguous, emergent, and uncertain systems. *System of Systems Engineering* (SoSE) is an example of such an approach. A key aspect of SoSE is the coordination and the integration of systems to enable 'system-of-systems' capabilities greater than the sum of the capabilities of the constituent systems. However, there is a lack of qualitative studies exploring how coordination and integration are achieved. The objective of this research is to revisit SoSE utility as a potential multidisciplinary approach and to suggest 'governance' as the basis for enabling 'system-of-systems' coordination and integration. In this case, 'governance' is concerned with direction, oversight, and accountability of 'system-of-systems.' 'Complex System Governance' is a new and novel basis for improving 'system-of-system' performance through purposeful design, execution, and evolution of essential metasystem functions.'

Keywords: complex system governance; general systems theory; system pathology; system-of-systems; systems philosophy; systems thinking

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1. Introduction

The operating landscape for systems in the 21st century is characteristically ambiguous, emergent, and uncertain. These characteristics affect the capacity and performance of engineered systems/enterprises including critical systems (e.g., energy and transportation) upon which society must depend [1–5]. In response, there are increasing calls for multidisciplinary approaches capable of confronting the elements of ambiguity, emergence, and uncertainty. This research places emphasis on exploring *System of Systems Engineering* (SoSE) [6–14], and evolution of the field to increase effectiveness as a multidisciplinary approach. Our knowledge and developments of the SoSE field lag in the pace of technological innovation [10,15]. More specifically, there is an excessive emphasis on technology development, which is outpacing our understanding (and development) of the more holistic integration of technologies across the range of socio-technical-political influences. This notion supports recent findings on research activities in the SoSE domain [16]. These findings suggest a lack of consideration of the holistic integration of multiple systems across technology, human, organizational, managerial, and political dimensions as a subject of 'system-of-systems' research.

A complement to our lag in knowledge and development of the field of SoSE is current realities related to increasing risks, threats, and vulnerabilities in society's critical systems of energy, telecommunication, water supply, agriculture, public health, transportation, and space. For example, in 2015, Bitfinex, a Bitcoin exchange based in Hong Kong, was hacked, losing about $400,000.

In 2016, the same entity lost about $73 million more when it was stolen from accounts of customers [17]. Unforntunatelty, such vulnerabilities are not limited to the banking systems. There are well documented in, among others, water systems [18], energy systems [19], and telecommunication systems [4]. Unfortunately, the reality is that these conditions (and failures) will escalate and accelerate. Simply stated: "the frequency and magnitude of organizational failures and the subsequent impacts are increasing at an alarming rate" [20]. Therefore, it is understandable to expect increasing interest in operating states of society's infrastructure systems, including calls for the development of methods and tools capable of addressing current and emerging risks, threats, and vulnerabilities [1].

A compliment to such efforts can also include classification of threats involving (i) natural, technical, and malicious threats [3]:

- Natural threat—revolving around 'natural' events such as earthquakes, floods, hurricanes, fires, and extreme heat. The occurrence of such events leads to incapacity (and disruption) of critical systems. They also lead to the loss of property and life.
- Technical threat—revolving around 'engineered systems' and involving human accidents and errors. Engineered systems include elements of ubiquitous computing and information and telecommunication systems, which are increasingly embedded in many aspects of society. Humans are incapable of creating 100% reliable systems, and as such, engineered systems unintentionally fail.
- Malicious threat—these are threats revolving around intentional failure of critical systems. Intentional failure of systems involves elements of acts of terrorism, insider threats, sabotage, and even state-sponsored attacks on critical systems.

This classification can become an initial step in dealing with threat identification, preventing, protecting, mitigating, and recovering from an attack. These activities must be undertaken 'systematically.' An ideal systematic approach (i.e., methodology) would need to have the ability to address issues (e.g., threat) at the individual system-level as well as issues at the 'system-of-system' level. Issues at the 'system-of-systems' level include elements of coordination and integration. In this research, we examine current methodological approaches for their ability to address 'system-of-system' level issues of coordination and integration.

The objective of this study is twofold: (i) revisiting utility associated with SoSE as a multidisciplinary approach and (ii) to suggest 'governance' as the basis for dealing with 'system-of-systems' level issues. In this case, 'governance' as a key aspect of 'system-of-system' is focused on enabling greater capability (including coordination and integration) beyond constituent systems. Additionally, governance is concerned with providing direction, oversight, and accountability of 'system-of-systems.' However, there is a lack of qualitative studies indicating how coordination and integration are achieved.

To fulfill the objective of this research, the remainder of this paper is organized as follows. Section 2 makes a case for the need for coordination and integration by examining the nature of the operating landscape for 21st century critical systems. Section 3 addresses the utility associated with 'System-of-Systems' Engineering as a multidisciplinary approach with the potential for dealing with challenges at the 'system-of-systems' level. Section 4 provides a discussion on 'governance' and how it can be used to enhance coordination and integration. The concept of 'governance' is discussed in the context of the emerging field of 'Complex System Governance.'

2. The Nature of the Operating Landscape for 21st Century Complex Systems

There is a general understanding that 'traditional scientific' methods are ill-equipped to address complex phenomena. Traditional scientific methods are rooted in a reductionist mindset and grounded in a 'mechanistic' view of the world, and as suchm they are unable to confront "problems confronting humanity at this stage in our history (poverty, violence, crime, environmental degradation and nuclear weapons … terrorism) … and cannot be understood or resolved in isolation" [21] (p. 430). Similar thoughts are expressed by Capra [22], Laszlo [23], von Bertalanffy [24], and Warfield (as cited in Francois [25]).

For example, von Bertalanffy [24] (p. 409) submits:

> "This method [scientific method] worked admirably well insofar as observed events were apt to be split into isolable causal chains, that is, relations between two or a few variables. It was at the root of the enormous success of physics and the consequent technology. But questions of many-variable problems always remained."

Meanwhile, Laszlo [23] (p. 17) suggests:

> " ... traditional reductionism sought to find the commonality underlying diversity in reference to a shared substance, such as material atoms, contemporary systems theory, seeks to find common features in terms of shared aspects of organization."

Similarly, Capra [22] (p. 36) establishes:

> "They [systems] arise from the 'organizing relations' of the parts-that is, from a configuration of ordered relationships that is characteristic of that particular class of organisms, or systems. Systemic properties are destroyed when a system is dissected into isolated elements."

Finally, Warfield as cited by Francois [25] (p. 89) postulates:

> "It is only within the last two hundred years and in a sense almost within this generation that man has become widely conscious of his own societies and of the larger sociosphere of which they are part."

These views suggest a need to understand and develop systems laws, principles, and theorems that govern complex systems with an emphasis on holistic thinking supported by ontology, epistemology, and even the nature of man and values. Moreover, there is a need to consider the nature of complex systems and their environment. Complexity is not only a feature of a system, it also involves the environment of the system, the observer of the system and their interplay [26–29]. Furthermore, complexity can take the form of organized simplicity, chaotic simplicity, organized complexity, and chaotic complexity [26] and is complemented by MacLennan's [30] notions of Complex Adaptive Systems and Khalil's [31] nonlinearity. Further clarification of complex systems is provided through the properties of complex systems [32].

Finally, a need for a more 'sociosphere' view of the world coupled with the nature of systems and their environment, suggests a need to see system 'wholes' rather than system parts and a more systemic view of the world is "based on an understanding of our fundamental interconnectedness and interdependence, with each other and with all of life" [21] (p. 430). A more succinct characterization of the operating landscape for the 21st century systems is provided [2]:

- Ambiguity—addressing a lack of clarity in understanding and interpretation of complex systems and their context using boundary conditions. A boundary separates a system from its environment [33]. Increasing difficulty in clearly demarking systems, their environments, problem situations, and context as well as their interpretation for understanding/analysis.
- Complexity—dealing with a high number of intricately interconnected systems such that complete understanding and control are impossible. For example, in dealing with a transport system that includes automobiles, trains, planes, watercraft, and pedestrians, a complete understanding of each system and interaction, while desirable, is impossible.
- Emergence—dealing with models of systems exhibiting properties as a whole entity deriving from its component activities and their structure, but cannot be reduced to components [34,35]. The properties and behaviors might be known and experienced. However, there is a lack of ability to predict such behavior.

- Interdependence—addressing bidirectional relationships existing among systems in which the state of each system is influenced by the state of interconnected systems [36]. Interdependence is exhibited in all aspects of society including people, animals, organizations, technologies, etc. creating intricate relationships (i.e., links) that are not obvious.
- Uncertainty—addressing the incompleteness of human knowledge of complex phenomena leading to doubt concerning the cause–effect relationships between decisions and actions. Given the presence of ambiguity, complexity, emergence, and interdependences, decisions and actions are taken without full knowledge of systems. This uncertainty creates doubt regarding the relationships between decisions and actions.

At this point, two critical points are emphasized: First, to gain knowledge in such systems, coordination and integration are essential concepts. This argument is supported by von Bertalanffy [24] (p. 410), who states, "Since the fundamental character of the living thing is its organization, the customary investigation of the single parts and processes cannot provide a complete explanation of the vital phenomena. This investigation gives us no information about the coordination or parts and processes." Additionally, the operating landscape of our systems is embedded in ambiguity, complexity, emergence, interdependences, and uncertainty. Phenomena need to be examined in the context of a systems operating environment. Second, even within the challenges of the 21st century operating landscape, there must be appropriate means (i.e., methodologies and frameworks) for dealing with complex systems and their problems within the operating environment. A key aspect of an ideal methodology is the ability to address 'system-wide' issues. Following these two arguments, the following questions are appropriate:

1. How do coordination and integration take place when dealing with complex phenomena?
2. What methodological approaches could be used to address coordination and integration?

For the present investigation, coordination and integration involve multiple complex autonomous systems, their resources, and capabilities to enable new functionality, performance, and missions exceeding functions, performance, or mission of the individual constituent systems. A methodological approach is used to explore means for coordinating and integrating systems and is ultimately responsible for "gaining knowledge about systems" [37] (p. 3) and must include "procedures for gaining knowledge about systems and structured processes involved in intervening in and changing systems" [38] (p. 134). The remainder of this research focusses on these two ideas starting with methodological approaches. We revisit the utility associated with System of Systems Engineering (SoSE) concerning enabling greater capability (including coordination and integration) beyond constituent systems. Moreover, 'governance' is suggested as the basis for dealing with current realities affecting the performance of systems. We now shift examination of methodologies that have a basis in systems and have proven successful in addressing complex systems and their issues.

3. Methodological Approaches for 21st Century Systems

First, there is no shortage of methodological approaches for dealing with complex systems, situations, and their problems. Table 1 provides a summary of methodologies grounded in systems theory and proven over time to be effective for design and resolution of complex system problems. They each offer a specific set of tools and perspectives to facilitate system problem solving to addresses different aspects of system design, analysis, operation, and maintenance of complex systems and their problems. They are all capable of generating success. However, these approaches are also capable of generating failure.

Table 1. Systems-based methodological approaches.

System Method(ology)	Major Themes	Primary Author(s)
Organizational Cybernetics	Diagnosis of structural system functions, relationships, and communications channels necessary for any system to maintain existence	[39–41]
Sociotechnical Systems	Work system analysis and redesign based on joint optimization of the social and technical subsystems for performing work	[42–44]
Systems Engineering	Structured formulation, analysis and interpretation of the technical, human, and organizational aspects of complex systems to address needs or resolve problems subject to cost, schedule, and operational performance constraints	[45,46]
System Dynamics	Computer modeling and simulation approach to understanding the relationships and underlying behavior of complex systems	[47,48]
Operations Research	An analytical approach to problem solving and management based on the determination of the mathematical optimal, or most efficient, means of achieving an objective.	[49]
Soft Systems Methodology	A process of inquiry focused on the formulation of ill-structured problems appreciative of multiple perspectives	[50]
Interactive Planning	Continuous organizational planning to design desirable futures and develop strategies to achieve that future through participation, management structures, planning, and process	[51]
Total Systems Intervention	A system problem-solving approach based on creative thinking, appropriate method selection, and implementation of method-based change proposals to resolve complex issues	[52]
Strategic Assumption Surfacing & Testing	Focuses on the resolution of ill-structured problems by identifying multiple stakeholders, their assumptions, and engaging in dialectical debate over proposed strategies to develop a higher-level course of action	[53]
Critical System Heuristics	A process of critical reflection based on a set of boundary questions that examine the legitimacy of designs by contrasting what "is" proposed versus what "ought" to be	[54]
Organizational Learning	Makes explicit individual and organizational models that enable organizations to make explicit and test tacit structures and patterns which generate system behavior	[55,56]
Project Management	Structuring and design of work to produce products and services subject to cost, schedule, and performance constraints	[57,58]
System-of-Systems Engineering	An approach for designing, analyzing, operating and transforming metasystems, composed of multiple embedded semiautonomous subsystems	[10,13]
Complex System Governance	An approach based on the design, execution, and evolution of nine metasystem functions. These provide control, communication, coordination, and integration of complex systems	[11]
Gibson's Systems Analysis Methodology	Provides six iterative phases to study complex systems problems, including System Goals, Ranking Criteria, Alternative Development, Alternative Ranking, Iteration, and Action	[59]

Two conclusions can be presented from this listing. First, each methodology has a purpose and is selected for use based on the context of the problem situation at hand and the purpose of analysis [60,61]. Second, the methodological approaches of 'System-of-Systems Engineering' and Complex System Governance' align with the idea of addressing 'system-wide' issues. For example, a key characteristic of 'system-of-systems' is 'geographical distribution.' In this case, individual systems are 'developed using centrally directed development efforts in which the component systems and their integration are deliberately, and centrally, planned for a particular purpose' [62]. The focus is not on elements (i.e., issues) of each system. Moreover, in 'Complex System Governance,' emphasis is on governance on two elements: (i) 'metasystem' functions, which are above and beyond system-level functions, and (ii) coordination, control, communication and integration beyond individual systems [11]. Both methodologies, System of Systems Engineering and Complex System Governance, are relevant in addressing 'system-wide' issues.

System of systems engineering (SoSE) continues to emerge as a multidisciplinary field to address complex problems in diverse domains such as global earth observation systems [9], software-intensive systems [63], carbon emissions [64], public policy decision making [65], data mining [2], risk analysis [66], maritime transportation [67], defense [14,68] and healthcare [8]. Amid increasing ambiguity, complexity, emergence, interdependence, and uncertainty, SoSE offers a means to attain a capability, mission, and outcomes beyond those individual systems [13]. Maier's [69] research provides characteristics of 'system-of-systems' typified by operational independence, managerial independence, evolutionary development, emergent behavior, and geographical distribution.

Furthermore, the landscape of 'system-of-systems' problem accentuates several key elements (i.e., holistic problem space, ambiguity, uncertainty, highly contextual, emergent, non-ergodic, and non-monotonic conditions). Table 2 describes these elements as postulated by Sousa-Poza et al. [13].

Table 2. The problem landscape for system-of-systems.

Threat Classification	Brief Description
Holistic problem space	The nature of the system-of-systems problem space requires consideration of the technical, human/social, managerial, organizational, policy, and political dimensions
Ambiguity	The difficulty in clearly demarking problem boundaries, as well as their interpretation, is an inherent characteristic of 'system-of-systems' problem domain
Uncertainty	System-of-systems problems are not tightly bound, flexing as additional knowledge of the situation is developed
Highly contextual	Consideration of circumstances, conditions, factors, and patterns that give meaning and purposes to 'system-of-systems.'
Emergence	System-of-systems behavioral and structural patterns, their interpretations, knowledge, understanding, and conditions are in constant flux
Non-ergodicity	A phenomenological condition of having no defined states or discernible transitions between states
Non-monotonicity	Increases in knowledge are not reciprocated by increases in understanding. Under this condition, decisions are defeasible or tentative

Operating under such conditions requires coordination, control, communication, and integration beyond the capacity of individual systems [70–72]. Still, there is a lack of information as to how 'coordination, control, communication, and integration' is accomplished for 'system-of-systems.' In the following section, an attempt to address this issue through 'governance' is articulated. Governance represents a new and novel perspective to advance prospects for System of Systems Engineering.

4. ‘Governance’ for System-of-Systems

There are a plethora of definitions for ‘system-of-systems’ [73]. An attempt to create yet another is beyond the objective of present efforts. However, the characteristics of ‘system-of-systems’ coupled with ‘system-of-systems’ ‘problem landscape could be useful in providing context and purpose for the need to address coordination, control, communication, and integration. First, we adopt a definition by Stevens Institute of Technology [73]. System of Systems Engineering (SoSE) is

> *“The process of planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system-of-systems capability that is greater than the sum of the capabilities of the constituent parts. This process emphasizes the process of discovering, developing, and implementing standards that promote interoperability among systems developed via different sponsorship, management, and primary acquisition processes”* [73] (p. 3).

In this definition, it is clear that coordination and integration are necessary to yield the capability beyond those of the constituent systems. However, coordination and integration are supplemented by elements of control (i.e., it permits the system to adapt and remain viable) and communication (i.e., a key instrument in system survivability and viability) [74]. However, there is a lack of information as to how ‘coordination, control, communication, and integration’ is accomplished for ‘system-of-systems.’ Extending the academic view of SoSE is the emerging research of ‘Complex System Governance,’ where the main concern of ‘governance’ is addressing direction, oversight, and accountability in ‘system-of-systems.’

Complex System Governance (CSG) is a methodological approach to improve system performance through purposeful design, execution, and evolution of essential metasystem functions [12,74–79]. CSG emphasizes communication, control, coordination, and integration of complex systems through the effective performance of the metasystem functions.

The CSG approach is grounded in General Systems Theory, Management Cybernetics, and Governance. General Systems Theory (GST) emerged as an approach for discovering ‘trends’ in various disciplines [80]. A key objective of GST is to provide an alternative to the reductionist approach closely aligned with the scientific method, which holds that a complex organism is nothing more than the sum of its parts [23]. Although there is no universally accepted definition for GST, the aspect of GST describing isomorphic concepts, laws, principles, and theorems capable of explaining behavior and performance applicable to different systems is well documented in the literature [7,81–88]. The most recent research suggests over 80 laws, principles, and theorems for GST [86]. CSG relies on laws, principles, and theorems for explaining the governance of complex systems.

The second element of CSG is Management Cybernetics, which was originally defined as the science of ‘control and communication’ [89]. A central element of Management Cybernetics ‘system viability’ is captured in Stanford Beer’s Viable System Model (VSM) and its essential five subsystems necessary for continued system existence [39–41,90–92]. CSG extends the VSM view of system viability functions (See Table 3). Figure 1 provides a summary of CSG metasystem functions for CSG, as described by Keating and Bradley’s [93].

Again, the term ‘metasystem’ is deliberately used in CSG to denote roles above those of individual systems [94–96]. True to the issue at hand (i.e., addressing issues above and beyond system-level), the CSG framework does not address functions (and issues) at the individual system level, but instead is focused on the integrated ‘set’ of systems integrated as a ‘system of systems’.

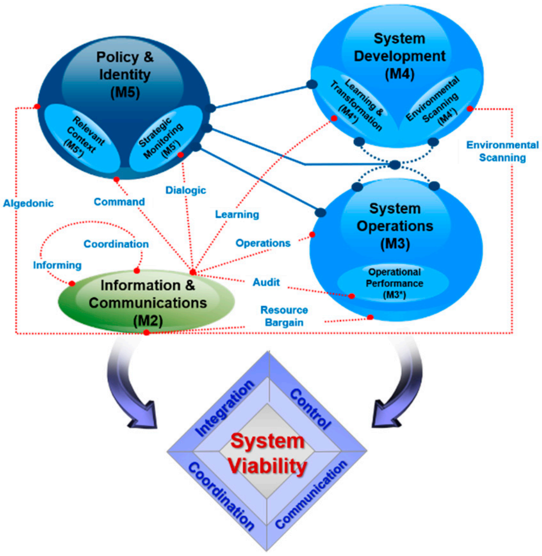

Figure 1. Complex system governance (CSG)'s metasystem system functions.

Table 3. The problem landscape for system-of-systems.

Areas of Concern	Metasystem Function	Brief Description of the Primary Role
System Identity	Policy and Identity (M5)	Focusing on overall steering and trajectory for the system in the fulfillment of its mission. This function maintains identity and balance between current and future focus
	System Context (M5*)	Focusing on the specific context within which the metasystem is embedded. Context includes circumstances, factors, conditions, or patterns that enable or constrain execution of the system
	Strategic System Monitoring (M5′)	Focusing on oversight of the system performance indicators at a strategic level, identifying performance that exceeds or fails to meet established expectations
System Development	System Development (M4)	Maintaining models of the current and future system, concentrating on the long-range development of the system to ensure the future viability
	Learning and Transformation (M4*)	Focusing on the facilitation of learning (i.e., first-order and second-order) based on correction of design errors in the metasystem functions to enable planning for metasystem transformation
	Environmental Scanning (M4′)	Focusing on designing, deployment, and monitoring of sensor for environment trends, patterns, or events that can have implications on the current state of the system and future viability of the system
System Operations	System Operations (M3)	Focusing on the execution of the day-to-day system activities to ensure that the overall system maintains the established performance levels
	Operational Development (M3*)	Focusing on monitoring system performance to identify and assess aberrant conditions, exceeded thresholds, or anomalies
System Information	Information and Communication	Focusing on designing, establishing, and maintaining the flow of information (and consistent interpretation of 'messages' through impropriate communication channels) necessary to execute metasystem functions

CSG functions are not new. To a great extent, many of these functions are performed in many organizations. A general approach might examine organizational performance along three axes: (i) existence of functions, (ii) execution efficiency, and (iii) enabling mechanisms. Moreover, Beer also postulated that "viable systems of all kind are subject to breakdown. Such breakdowns may be diagnosed, simply in the fact that some inadequacy in the system can be traced to malfunction in one of the five subsystems, where in turn one of the cybernetic features … will be found not to be functioning" [90] (p. 17). In this case, management must pay attention to the configuration and execution of systems to avoid experiencing governance-based pathologies (aberrations from normal/healthy system function design/execution). Such pathological conditions include recursive pathology, identity pathology, subsystems 2–4 mismatch pathology, and metasystem pathology [90]. Emerging research on system pathologies, grounded in General Systems Theory (CSG is grounded in General Systems Theory), suggests well over 100 system theory-based pathologies [97–99]. In seeking to cluster pathologies, there are eight (8) distinctive inductively developed metasystem pathologies that have emerged out of a meta-synthesis of categorizations of GST [88]:

- ***Systemic dynamic pathology***—a set of systemic pathological issues affecting system performance from the view of the dynamic nature of complex systems. GST suggests that complex systems continuously interact with other systems to produce performance. There is a need to consider the interactive nature of complex systems, their subsystems, and the interplay with their environment.
- ***Systemic goal pathology***—a set of systemic pathological conditions affecting system performance in terms of goals. This theme emerged from GST concepts suggesting that complex systems have goals, and those goals can be achieved through effective use of certain GST concepts.
- ***Systemic information pathology***—a set of systemic conditions affecting a system in terms of information and communication. GST suggests that the performance of a complex system is related to the ability to create, transmit, receive, and extract meaning from information (i.e., messages).
- ***Systemic process pathology***—a set of systemic conditions affecting processes of complex systems. This theme emerges out of concepts of GST describing several processes (internal and external) to the system that must take place to ensure system development, stability, and continued viability.
- ***Systemic regulatory pathology***—a set of systemic conditions affecting a system in terms of control and regulation. This theme emerges from concepts of systems theory, suggesting that a certain level of control is required to guide complex system development and enabling growth, stability, and continued viability.
- ***Systemic resources pathology***—a set of systemic conditions affecting a system in terms of resources and resource utilization. This theme emerges from concepts of GST suggesting a need for resources in enabling system development. Moreover, how resources are utilized can harm system productivity.
- ***Systemic structure pathology***—a set of systemic pathological conditions about the structure of a system. GST suggests that all systems can be characteristically organized in certain patterns and relationships to enable achieving maximum performance.
- ***Systemic understanding pathology***—a set of systemic pathological conditions related to the theme of human understanding of complex systems. This theme is developed from GST concepts suggesting that the human capacity for understanding plays a major role in how one deals with complex systems.

A comprehensive description of each (meta)pathology, including individual attributes (i.e., related systems theory-based pathologies), detailed accounts of dimensions of pathologies, and relation to GST concepts, can be found elsewhere [88]. Beyond system pathologies for 'system-of-systems' [100], concepts of pathologies can be examined for systems engineering [101] as well as processes in different systems [102]. However, projecting pathologies (and for purposes) uniqueness to CSG, emphasis must be placed on risks and vulnerabilities (i.e., pathologies) affecting integration and coordination (see CSG functions) in 'system-of-systems.'

A final part of the CSG framework is 'governance.' In this case, 'governance' revolves around the three elements: direction, oversight, and accountability. Governance entails sustaining a coherent identity and vision that supports coordinated decision-making including actions, interpretations, and strategic priorities (direction). Governance also involves provision for system control, communication, and integration of systems and their entities (oversight). Finally, governance involves accountability for system development in the form of efficient utilization of resources, monitoring performance, and exploration of aberration conditions.

At this point, it is worth mentioning that development for 'governance' in 'system-of-systems' does not come by accident. It has to be purposely designed. Table 4 provides a summary of the three contrasting forms of 'system-of-system' development for 'governance.' It should be evident that 'accretion' and 'self-organization' are the least preferred approaches.

Table 4. Three contrasting forms of system development.

Type of System Development	**Characteristics**			
	Structure/Behavior/ Performance	**Development Energy Consumption**	**Primary Focus for Improvement**	**Design Preference**
Accretion	Fragmented	Medium	Isolated/Piecemeal	Ad-hoc
Self-Organizing	Emergent	Low	Self-balancing/Laisse Faire	Unfettered
Purposeful	Designed	High	Holistic/Integrated	Intentional

Considering 'system-of-systems' functioning imperfectly as a real system operating to provide essential goods and services enabling public well-being, then it can/does operate under conditions characterized by high degrees of ambiguity, complexity, emergence, interdependence, and uncertainty. These conditions include elements of risks and vulnerabilities inherent to all systems and capable of shifting over time and shifts in environment/context. Moreover, because of these conditions, the focus should be on the cross-cutting 'system-of-systems' issues that negatively impact higher level system of systems performance in substantial ways. This does not suggest ignoring constituent system-level issues. Rather, those issues are entrusted and relegated to the system level for resolution, using accessible system-level methodological approaches. A unique benefit of CSG governance is the development and execution of capabilities to address issues beyond individual systems. These issues can take many different forms including such recognizable descriptions of opportunities and threats [103,104].

5. Research Implications and Directions

The application of CSG to advancing 'system-of-systems' is still emerging and targeted to enable practitioners to better address the 'coordination and integration' of individual systems to enable attainment of capability, mission, and outcomes beyond those individual systems. These outcomes might involve dealing with current and emerging risks and vulnerabilities stemming from the problems associated with a landscape marked by increasing levels of ambiguity, complexity, emergence, system interdependence, and uncertainty. Although 21st century systems must operate under such conditions, there remains a lack of information as to how 'coordination, control, communication, and integration' are accomplished for 'system-of-systems.' In this research, we propose 'governance' for 'system-of-systems as a means for enabling 'coordination and integration' to achieve system of systems level capabilities that are greater than the sum of the capabilities of the constituent systems through the provision of direction, oversight, and accountability.

However, there remains fruitful research in particular to address how governance can be assessed. In this current stream of research, three related concepts are being explored:

- ***Existence of functions***—examining the degree to which the CSG functions exist for a given entity (system of systems). While, functions will be performed by all viable (existing) systems, they may be existing in varying degrees of tacit/explicit, formal/informal, and purposeful/self-organized designs. It is important to have a sense to the existence of functions.
- ***Execution efficiency***—examining the extent to which CSG functions are performed in a well-organized manner. For a given entity, such functions may be existent, but poorly executed (performed inefficiently wasting resources).
- ***Enabling mechanisms***—examining mechanisms used in the execution of CSG functions. Mechanisms are the basic building blocks of governance for performing functions. For a given entity, poor execution could be linked to inappropriate kind/number/execution of mechanisms.

Moreover, there remains a need for systematic methods and tools for dealing with risks and vulnerabilities created across the spectrum of pathologies indicative of inadequacies in the design, execution, or development of a system of systems. Such systematic methods can be used for the identification of threats (natural, technical, and/or malicious), classification as either system-level or 'system-of-system' issues, and the eventual basis for responses to prevent, protect, mitigate, or recover from such threats.

The development and application of CSG to advance 'system-of-systems' is in its infancy. There remains a need for furthering current research (case applications and development of methods and tools) to enhancing the utility of governance (CSG) in different types of 'system-of-systems.'

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